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DEVELOPMENT OF THE SEISMIC INPUT FOR USE IN THE SEISMIC SAFETY MARGINS RESEARCH PROGRAM

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DISCLAIMER

DEVELOPMENT OF THE SEISMIC INPUT FOR USE IN THE SEISMIC SAFETY MARGINS RESEARCH PROGRAM*

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SUMMARY

This paper briefly outlines the overall systems approach being developed for the Seismic Safety Margins Research Program. The unique features of the approach being taken to reduce the uncertainty in the seismic input for this program are discussed. These unique features will include extensive use of expert opinion, earthquake rupture simulation studies and the way in which the seismic hazard is incorporated into the overall systems analysis. Some very preliminary results are also given for the Zion site which is the power plant chosen for analysis in Phase I of the program.

INTRODUCTION

Lawrence Livermore Laboratory (LLL) is currently engaged in a large multi-year seismic research program, entitled Seismic Safety Margins Research Program (SSMRP) (1), for the U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research.

The objectives of the SSMRP are to estimate the conservatisms in the Standard Review Plan (SRP) seismic safety requirements and to develop improved requirements. The approach to achieve these objectives is to develop probabilistic methodology that more realistically estimates the behavior of nuclear power plants during an earthquake. In the first phase of this program, this methodology will be developed for a specific nuclear power plant, Zion I, located a little north of Chicago, Illinois. The developed model will be used to perform sensitivity studies to gain engineering insights into seismic safety requirements. The failure probability of structures, systems, and components and the probability of radioactive releases over a range of earthquake levels will be used to help determine priorities for the future research.

The overall probabilistic based system model used in the SSMRP contains various methodologies. They are seismic input, site response,

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soil-structure interaction (SSI), structure and subsystem response, combination of seismic and nonseismic loads, failure assessment, event/fault tree and system analysis.

One of the unique features of the overall program is the manner in which the seismic hazard is incorporated into the overall systems model. Time histories are developed and input directly into the SSI model. These time histories will be characterized by peak acceleration and a spectral shape parameter. Statistics of structural response will be developed from these time histories conditional on the occurrence of a given peak acceleration and spectral shape parameter. The probability of occurrence of a given peak acceleration and spectral shape parameter pair and the statistics of structural response are input into the overall systems model along with component fragilities and event/fault trees to compute the probability of release of radioactive matter. The approach used for the overall systems model is described in Ref. (2).

It is important that the uncertainty in the definition of the seismic hazard be reduced to a minimum because all system failures are conditional on the probability of a given peak acceleration and spectral shape parameter pair. Clearly it will not be simple to reduce the uncertainty in our estimtes of the seismic hazard. One of the main goals of Phase I of our program is to attempt to bound the uncertainty associated with the key parameter of the hazard model. We then will determine which parameters have the most influence on the risk. This will set the necessary research goals for Phase II of the program.

In this paper we deal with the probabilistic development of the seismic input and the uncertainty associated with our estimates of the seismic ground motion at the Zion site. We also outline our approach to bounding and assessing the uncertainty in the various parameters which govern the seismic hazard.

OVERALL APPROACH

Probabilistic estimation of seismic load parameters has received much attention recently. Once source release, transmission patterns, and site effects can be defined, estimates of the probability of exceeding different levels of any ground motion parameter can be generated. Various procedures are available for evaluating seismic exposure Ref. (3). Typically, these procedures consist of three parts:

- A source seismicity model.
- A ground motion generation model.
- An exposure evaluation model.

The difference between the procedures lies in the assumptions used in developing the model and in the methodology for applying the model. The assumptions and methodology used for some procedures may not adequately model the physical processes of earthquake occurrences and attentuation and, consequently, exposure estimates may differ significantly.

The key elements that must be included in the source seismicity model are:

- Earthquake source regions. This defines where the earthquakes occur relative to the site. For the eastern U.S., because it is a region of low seismicity, it is not possible to correlate earthquakes with faults, hence the earthquakes are assumed to occur randomly over large regions.
- Earthquake occurrence model. This defines the distribution of earthquakes in time and size (magnitude or intensity) for each source region.

The key elements that must be included in the ground motion model are:

- Relation between the earthquake size parameter and its potential to generate ground shaking.
- Attentuation of the ground motion from the earthquakes location to the site.
- Effect of the site's local geology on the ground motion.
- Spatial variation of the ground motion over the site and with depth.

These key parameters can be divided into two groups: 1) parameters for which no conceptual models or little direct data are available, e.g. source zones, largest earthquake in a source zone; 2) parameters for which conceptual models and/or sufficient data are available; e.g., parameters of the occurrence model, earthquake source models, attenuation of seismic energy. To bound/assess the uncertainty associated with the first group we must resort to using expert opinion and sensitivity studies. To bound/assess the uncertainty from the second group we are using computer simulation, a variety of statistical approaches and expert opinion.

Typical exposure evaluation models have the major limitation that estimates for only one ground motion parameter at a time can be made. This is a significant limitation for our purposes as we need time histories. For this reason we will use a Monte Carlo approach. To overcome the difficulty of needing a large number of trials we have modified the Monte Carlo approach. These the modifications are discussed in a later section of this paper.

EXPERT OPINION

As pointed out above certain key elements of source seismicity model can only be obtained by expert opinion. For other aspects there is some data and/or theory which can also be used, however, as discussed in Ref (4), it is still very useful to incorporate expert opinion into all facets of our model. Considerable care must be taken when using expert opinion so that opinion, data and theory are properly weighted, and to insure that one is not lulled into the feeling that our true state of knowledge is more certain than it in fact is. Although we are still in the process of exploring the best ways to make use of expert opinion in our analysis we have made considerable progress. Some of the key features of our approach to obtain and use expert opinion are:

- . Appropriate panels of experts are being formed.
- . Detailed written questionnaires are being used requiring several days to complete.
- . Experts are generally being paid.
- . Follow-up meetings/questionnaires are being used.
- . The input from each expert is being used in a separate. hazard analysis to gain insight into the uncertainty in the analysis as well as guidance to the best way to obtain a synthesis of the major results.

At this time two panels have been formed. The members of one panel are ten well known geoscientists knowledgeable about the eastern U.S. Each panel member was sent a questionnaire which dealt with the overall regional characteristics of the eastern U.S. Five areas were covered: 1) geometry and probability of existence of the earthquake source regions; 2) largest earthquake that could occur in each region; 3) earthquake occurrence model and parameters of model; 4) earthquake source models and attenuation; and 5) self ranking. See Ref. (4) for the highlights of our questionnaire. The experts responses were then encoded along with other data and studies. The seismic hazard was then developed for a number of eastern sites including the Zion site. A number of sites were examined to insure that the Zion site is reasonably generic.

The other panel that we have formed was a review panel which had four members -- two geoscientists and two engineering statisticians. The purpose of the review panel was to provide a detailed peer review of our first questionnaire; our initial encoding and incorporation of these results to make up our source seismicity models; and hazard evaluation. The panel provided us with suggestions for improvements which we are planning to incorporate into our final model.

In the near future a panel will be formed to address all facets of the ground motion model. In particular, we hope to develop acceptable ways to correct the strong ground motion data base for the lower attenuation in the eastern U.S.; and to reduce the uncertainty in the relation between earthquake magnitude, distance and ground motion parameters of interest.

DATA ANALYSIS/THEORETICAL MODELING

As noted above, sufficient data and/or theoretical models exist to help assess some of the key elements which are included in the analysis. Thus in addition to our effort on obtaining and incorporating expert opinion a number of specific studies have been undertaken to supplement/improve our current understanding in several areas. These include: (i) a strong earthquake ground motion data gathering/verification task; (ii) a task using the computer to simulate the earthquake rupture and (iii) several data analysis tasks.

In the space available we can only discuss a few key items. See Ref. (1) for details about all of the ongoing tasks. Here we want to discuss our computer simulation study which will allow us to model the significant differences in the earth's structure and Q between eastern and western U.S., and such earthquake parameters as: (i) stress drop (both dynamic and static); (ii) length and width of the rupture zone; (iii) rupture velocity and focusing and (iv) depth of energy release. The intent of this study is to assess the relative effect each of these parameters have on the ground motion at the Zion site for a range of the parameters and epicentral distances. Some parameters (Q), e.g., are known to be significantly different in the eastern U.S. as compared to western U.S. For other parameters there is a some potential that they are systematically different than for the set of earthquakes which make up the strong motion data set. We can use the computed relative difference in the ground motion between western and eastern U.S. and expert opinion to develop appropriate bounds for the ground motion from earthquakes in the eastern U.S.

Another important aspect of the earthquake simulation study will be to compute the spatial variation of the earthquake ground motion over the site. This variation can play an important role in the soil structure interaction analysis that will be performed, Ref. (5). Very little data exists from earthquakes which can be used to determine the variation of ground motion over the area the size of the foundation mat of a large nuclear power plant. This variation is a function of the earth's structure between the site and earthquake fault, the depth of the earthquake and mechanism of the earthquake. For Phase I, we will not be able to include all these factors. As time progresses a sufficient number of cases will have been run to determine how important the variation of ground motion over the site is and which parameters are causing the most significant variation.

We are exploring the use of ARMA models to develop time series for the earthquakes in our exposure evaluation model for input into the SSI analysis. Our first study, Ref. (6), indicates that the use of ARMA modeling is potentially very useful. Continued effort is ongoing in this area.

EXPOSURE EVALUATION MODEL

The exposure evaluation model we are going to use is a second generation improvement on the model discussed in Ref. (3). A number of significant improvements have been incorporated. First, the uncertainty of the seismic source regions are included by having a number of different models (one from each expert) and allowing some of the seismicity to be random over a larger background region. The number of earthquakes allowed to migrate is related to the probability of existence each expert assigned to the various source regions. This aspect of our model is under study and revision. Secondly, we have incorporated not only the uncertainty in the earthquake occurrence model; but, also, the uncertainty of the largest earthquake that can occur in each source region. The third major improvement is the introduction of a Monte Carlo simulation. We incorporated a Monte Carlo feature because in typical exposure evaluation models only one ground parameter at a time can be attenuated to a site. In our approach our exposure evaluation model will be evaluated in the usual manner to determine the mean rate of occurrence of earthquakes between $M_i \pm M/2$ and $R_i \pm R/2$ to form a matrix which spans the magnitude and distance ranges. The assumption here, in keeping with our lack of knowledge about the earthquakes of the eastern U.S., is that we can not distinguish between earthquakes in two different seismic regions provided that they have the same magnitude and are at the same distance. As our state of knowledge increases it is a simple manner to remove this restriction. Then, for each element of the M, R matrix, we will generate time histories via a Monte Carlo approach. The mean rate for each M, R entry relative to the other rates for each entry sets the probability of having any given time history. The time histories generated for each element of the matrix will have different accelerations and spectral shape parameters. For input into the system model the generated time histories will be sorted via peak acceleration and spectral shape parameter.

INITIAL RESULTS AND SUMMARY

We have completed initial studies and our results indicate the use of expert opinion to supplement the lack of data is a viable approach. Although very significant differences of opinion exists about most of parameters of the model, the overall net effect on the estimate of the seismic hazard is much less. This is illustrated by Fig. 1 which shows one part of our preliminary estimates of the seismic hazard at the Zion site. Shown in Fig. 1 is the 1000 year return period for the uniform hazard relative velocity spectrum for 5% damping. It is seen, for the shorter period range of interest for nuclear power plant seismic analysis, that there is only about a factor of two variation between all experts.

The unique features of our approach are: (1) our methodology to develop the seismic hazard will make extensive use of expert opinion, available data and modeling studies; (2) we will model the uncertainties in the boundaries of the source regions, earthquake occurrence model, largest earthquake for each source region, and attenuation of seismic energy; (3) the seismic hazard for use in the overall systems model will be given by two parameters which define the spectral level and shape and (4) the structural response statistics will be developed from appropriate sets of time histories. The same sets used to develop the seismic hazard curve.

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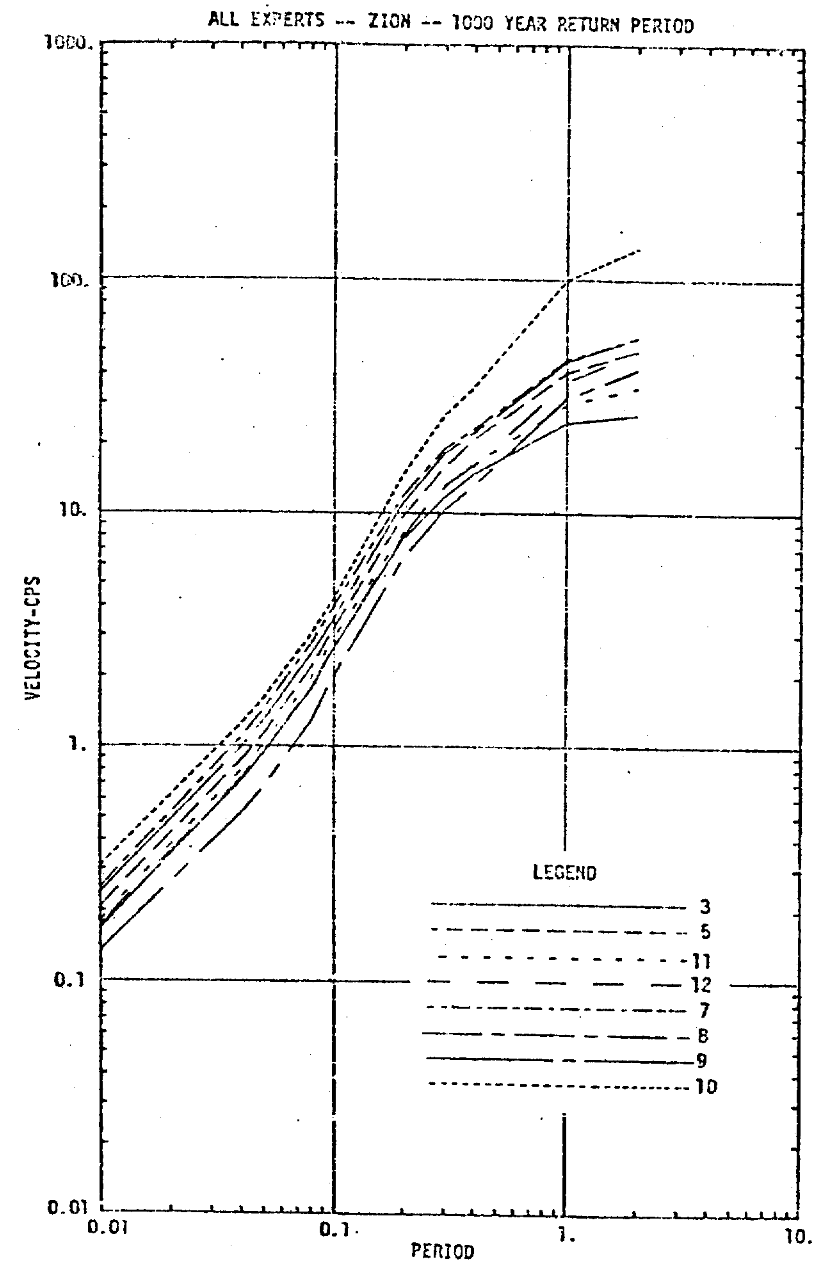

FIGURE 1

Preliminary estimates of the 1000 year return period for the 5% damped uniform hazard relative velocity spectra for each expert's model.